

HIGH EFFICIENCY EPITAXIAL GaAs/GaAs AND GaAs/Ge SOLAR CELL TECHNOLOGY USING OM-CVD*

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EXTENDED ABSTRACT

INTRODUCTION

The objective of this research program is to develop a technology for fabricating high-efficiency, thin-film GaAs solar cells on substrates appropriate for space and/or terrestrial applications. The approach adopted utilizes organometallic chemical vapor deposition (OM-CVD) to form a GaAs layer epitaxially on a suitably prepared Ge epi-interlayer deposited on a substrate, especially a light weight silicon substrate which can lead to a 300 Watt-per-kilogram array technology for space. The proposed cell structure is shown in Figure 1. The intermediate goals of the program are to investigate GaAs epilayer growth on single-crystal GaAs and Ge wafer substrates and to develop related cell-fabrication technology.

EXPERIMENTAL

GaAs layers were grown on (100) single-crystal GaAs substrates in a horizontal CVD reactor at 700 - 725°C with a growth rate of 0.2 micrometer/min. By alternately adding dimethylzinc and hydrogen sulfide to the gas stream as p and n- type dopants, a shallow n⁺/p homojunction GaAs structure was produced. The active p-layer about 2 micrometers thick was doped to $1-2 \times 10^{17} \text{ cm}^{-3}$, whereas the n⁺ layer about 500-1000Å thick was doped to $4 \times 10^{18} \text{ cm}^{-3}$ for low sheet resistance. Electroplated gold was used for grid and back surface contact coating and the anti-reflection coating was made by anodization. A similar configuration and process was used for GaAs cells fabricated on single-crystal Ge substrates.

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RESULTS AND DISCUSSION

High quality GaAs epi-layers have been obtained by using OM-CVD. Undoped GaAs films on Cr-doped substrates showed a Hall mobility as high as $8000 \text{ cm}^2/\text{v-sec}$ and an electron concentration of $3 \times 10^{14} \text{ cm}^{-3}$ at room temperature. The electron or hole concentration in the n-type or p-type GaAs epi-layers, respectively, was found to have a linear relationship to the dopant concentration in the gas stream. Although the maximum electron concentration in GaAs doped with hydrogen sulfide can reach $5.8 \times 10^{18} \text{ cm}^{-3}$, the mobility of electrons decreases when the concentration exceeds $4 \times 10^{18} \text{ cm}^{-3}$, so that the sheet resistance of the top n^+ layer would deleteriously increase instead of decreasing. The best energy conversion efficiency of 19.7% measured under simulated AM1 conditions (ELH lamp) was achieved with an n^+/p GaAs solar cell made on a single-crystal GaAs substrate with 1-cm^2 area, as shown in Figure 2. The values of open-circuit voltage (V_{oc}), short-circuit current density (J_{sc}) and fill-factor (FF) for this cell were about 0.988 volt, 25.6 mA/cm^2 and 0.78, respectively.

The GaAs epi-layers grown at 700°C or above on single-crystal Ge substrates were found to be heavily doped by the substrate, with $N_d \approx 10^{18} \text{ cm}^{-3}$ for undoped GaAs as determined by Hall measurements. To reduce this autodoping to an acceptable level (less than 10^{17} cm^{-3}) the growth temperature had to be lowered to 650°C or less. However, the surface morphology (as shown in Fig. 3 and Fig. 4) of GaAs grown on Ge was also found to be strongly influenced by the growth temperature, deteriorating as the temperature was lowered. In order to achieve good surface morphology and yet to avoid high autodoping, a method using sequential GaAs growths at two temperatures was developed. This involved using a higher temperature ($\sim 700^\circ\text{C}$) for initial nucleation continuous coverage and good morphology and a lower one ($\sim 650^\circ\text{C}$) for continued growth. By using this method, GaAs solar cells with an n^+/p shallow homojunction structure were made. The best cell exhibited an AM1 efficiency of 18.4% (Fig. 5), with other cells having efficiencies just a little less. The values of V_{oc} , J_{sc} and FF for this best solar cell are 1.0 V, 24 mA/cm^2 and 0.79, respectively.

Recently, thin epitaxial layers of GaAs, bright and shiny, were successfully grown by OM-CVD onto Ge epi-interlayers which were grown onto (100) Si substrates. X-ray diffraction measurements showed that the Ge interlayer and the GaAs top layer were completely single-crystal, having the same (100) orientation as the Si substrate. This is the first report of successful growth of this structure. After cleaving the substrate, SEM photographs of the cleaved surfaces clearly showed the uniform layered structure. Growth optimization, characterization measurements of the thin films, as well as solar cell fabrication and performance measurements will be done, the procedures and results for which will be reported at a later date.

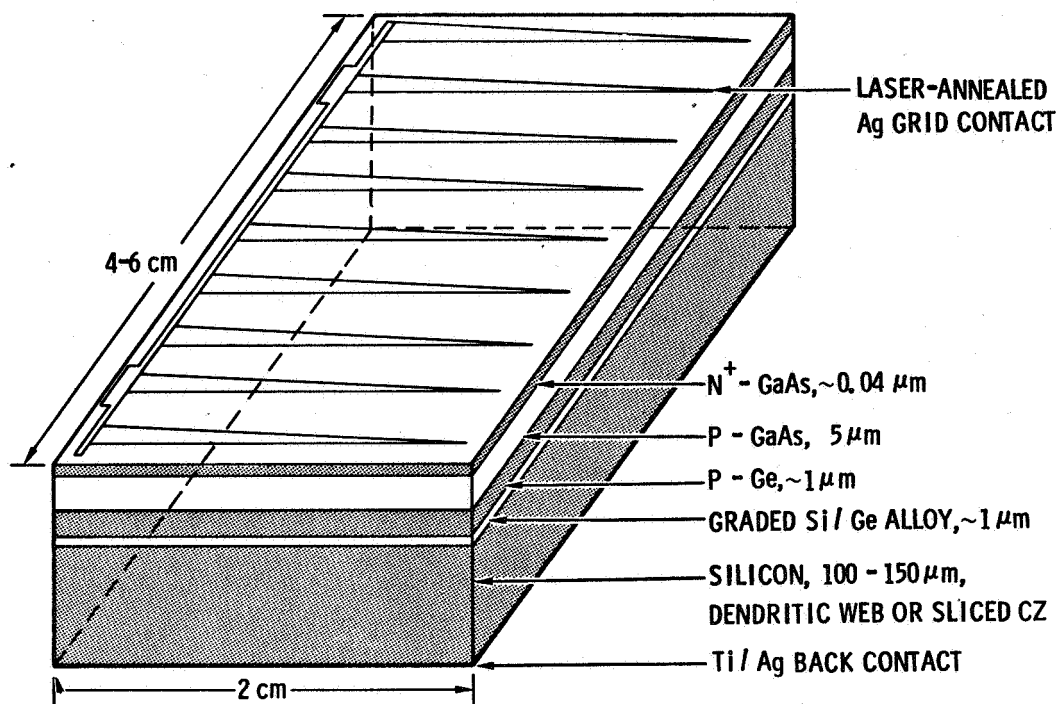


Figure 1. Light weight GaAs solar cell structure.

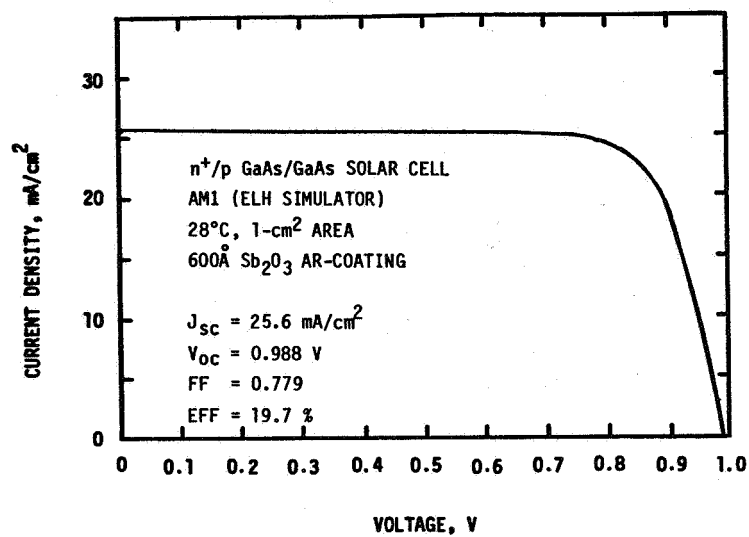


Figure 2. Light I-V characteristics of an n^+/p GaAs/GaAs solar cell.

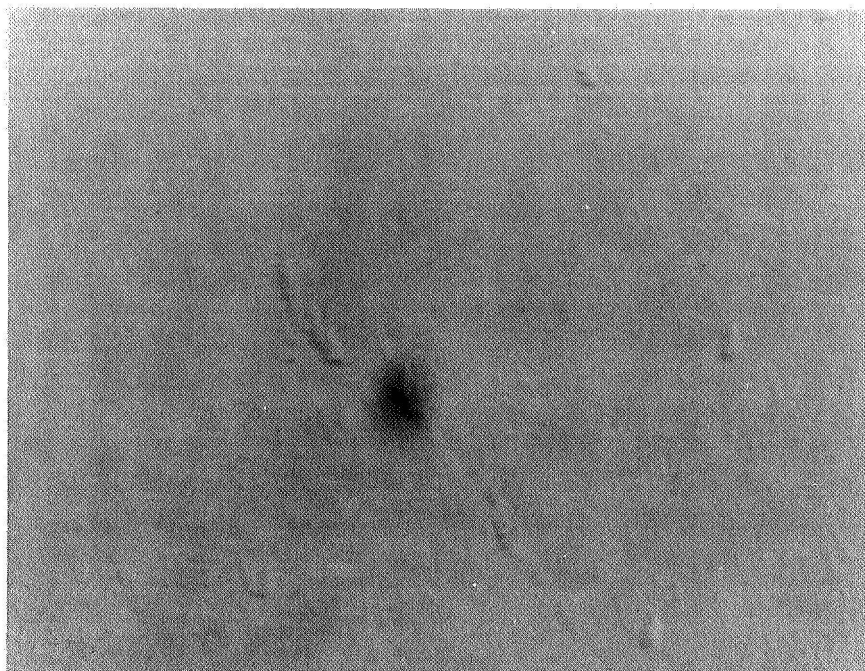


Figure 3. Photomicrograph (250X) showing surface morphology of GaAs epi-layer grown at 700°C on Ge substrate.

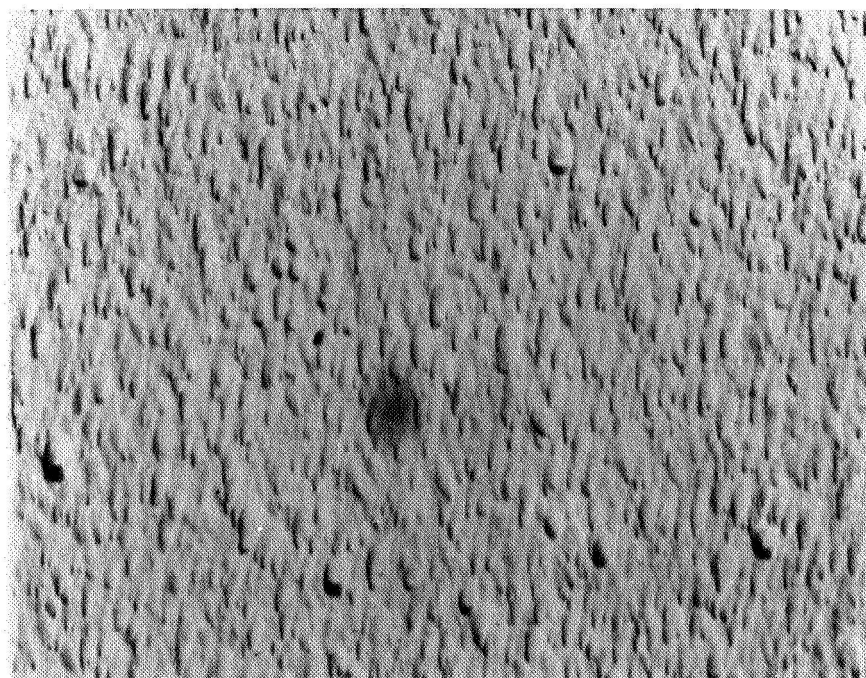


Figure 4. Photomicrograph (250X) showing surface morphology of GaAs epi-layer grown at 650°C on Ge substrate.

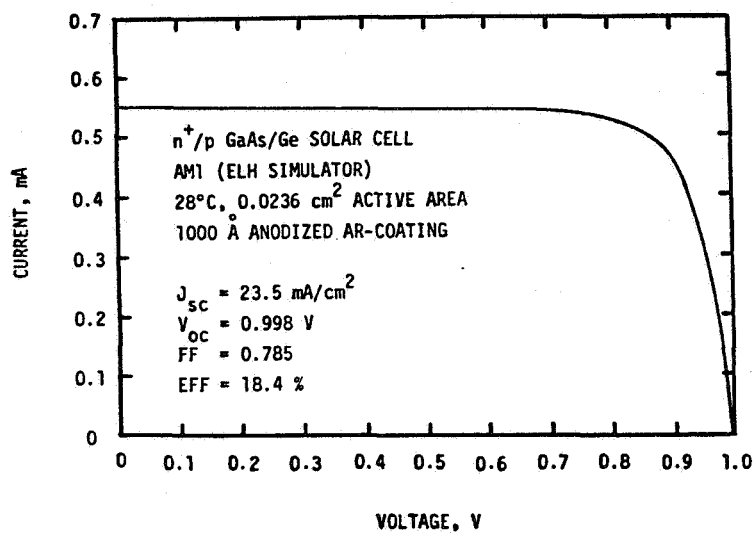


Figure 5. Light I-V characteristics of an n^+/p GaAs/Ge solar cell.